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(54) Title: METHOD AND APPARATUS FOR DATA TRANSFER AND STORAGE IN A HIGHLY PARALLEL COMPUTER NETWORK ENVIRONMENT

(57) Abstract

A method and apparatus for sharing a single storage device among an arbitrarily large number of parallel processes with typically no wasted memory space and continued operations even when an error or interrupt occurs is disclosed. In a networked computer system having a communication network connecting a primary storage device between one or more computer devices and a secondary storage device, when some type of interrupt is generated or an error condition occurs or is otherwise indicated, a transfer of data from primary to secondary storage is indicated. A state indicator having at least a non-backup and a backup state may be set to the backup state to indicate that a data transfer from the primary storage device to the secondary storage device should occur. Alternatively, the transfer from the primary to the secondary storage device can begin without the use of a state indicator. When the state indicator is in the backup state, a predetermined maximum number of processes will work on transferring data from the primary storage device to the secondary storage device. Other processes will transfer data from the computer to the primary storage device. The process which completes the transfer of data from the primary storage device to the secondary storage device then resets the state indicator to its normal state. Preferably, other processes which are already executing at the time when the state indicator is set to the backup state continue to execute to completion.

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METHOD AND APPARATUS FOR DATA TRANSFER AND STORAGE IN A HIGHLY PARALLEL COMPUTER NETWORK ENVIRONMENT

RELATED APPLICATIONS

This application is related to co-pending application entitled "METHOD AND APPARATUS FOR TRANSFERRING AND STORING DATA FROM AN ARBITRARILY LARGE NUMBER OF NETWORKED COMPUTER STORAGE DEVICES", filed concurrently herewith, which was commonly assigned or subject to an obligation of assignment to the same person at the time of invention.

FIELD OF THE INVENTION

This invention relates generally to data transfer and storage and more specifically to a method and system for sharing a single storage resource among a plurality of parallel processes.

BACKGROUND OF THE INVENTION

A computer or a network of computers may be connected to one or more backup storage devices to provide greater amounts of low cost storage onto which the computers can create archival or backup copies of their files for later recovery if the original files are lost or corrupted. Typically, data is copied from a computer first to a primary storage device and subsequently copied from the primary storage device to a lower cost, higher density secondary storage device such as a magnetic tape or an optical disk. Typically, the secondary storage device is slower than the primary storage device. The transfer of data from the primary storage device to the secondary storage device typically begins when the amount of used storage space on the primary storage device equals or exceeds a predetermined amount or percentage, known as a "high water mark".

The purpose of using a "high water mark" is to reduce the chance that substantially all of the memory on the primary storage device will be used up, thereby causing the primary storage device to become inoperative. The high water mark is set to a value which is based upon the rate of data coming into the primary storage device and the rate of data transfer from the primary storage device to the secondary storage device. Since the rate of incoming data to the primary storage device usually exceeds the rate of data transferred from that device to a secondary storage device, the high water mark, in effect, creates a buffer so that the memory of the primary storage device is not used up, causing that device to become inoperative.

Even with this buffer area, if the rate of data being written to the primary storage device exceeds the rate of data being transferred from that device to the secondary storage device, the primary storage device will become inoperative. Moreover, setting a low "high water mark" may reduce the chance that this will occur, at the expense of wasting storage resources on the primary storage device. However, even a low "high water mark" can not guarantee that the primary storage device will not fill up.

Additional problems arise when high water marks are used in a parallel processing computer system. Since the number of parallel processes is directly related to the rate of incoming data to the primary storage device, i.e. the more processes the faster the rate, the high water mark should be recalculated and adjusted as the number of parallel processes changes. These recalculations can be quite cumbersome and time-consuming and could still ultimately be inadequate.

On the other hand, not recalculating the high water mark when the number of processes changes can produce other problems. If the high water mark is not recalculated when the number of processes increases, then the rate of incoming data to the primary storage device may exceed the rate of data transfer from the primary device to the secondary device, because more processes are writing to the storage device. Similarly, when the number of processes decreases, not recalculating the high water mark may lead to wasted space, because the high water mark is set too low, creating a buffer having a larger size than necessary.

SUMMARY OF THE INVENTION

This invention provides a method and apparatus for sharing a single storage device among an arbitrarily large number of parallel processes with typically no wasted memory space and continued operation even when an error condition or interrupt occurs. Briefly, according to the invention, in a networked computer system having a communication network connecting a primary storage device between one or more computer devices and a secondary storage device, when some type of interrupt is generated or an error condition occurs or is otherwise indicated, a transfer of data from primary to secondary storage is initiated. The transfer may be initiated by setting a state indicator having at least a non-backup state and a backup state to the backup state to indicate that a data transfer from the primary storage device to the secondary storage device should occur. Alternatively, the transfer may be initiated by beginning the transfer of data from the primary to the secondary storage device without the use of a state indicator.

For example, when a process attempts to write data to a disk and encounters an error condition because there is insufficient disk space available to accommodate the write request, that process performs one of the following three actions. It begins transferring data from the primary storage device to the secondary storage device

without setting a state indicator. Alternatively, it begins transferring data from the primary storage device to the secondary storage device and sets a state indicator to the backup state to alert other processes that such a data transfer should occur. Otherwise, the process sets the state indicator to the backup state and does not begin transferring data from the primary storage device to the secondary storage device.

Parallel processes may be used to transfer data among devices connected to the network. Preferably, the number of processes working on transferring data from the primary storage device to the secondary storage device will be less than or equal to a predetermined maximum number of processes. The other processes will transfer data from the computer to the primary storage device. When a state indicator is used, the process which completes the transfer of data from the primary storage device to the secondary storage device then resets the state indicator to its normal state. Although, setting a maximum number of processes for performing data transfer operations between the primary storage device and the secondary storage device increases efficiency, the invention may be used without setting such a limit on the number of processes. Preferably, processes which are already executing at the time when the interrupt or error condition occurs and did not themselves encounter the error or interrupt continue to execute to completion.

Since a portion of the primary storage device's memory is not allocated as a memory buffer, the invention typically eliminates wasted memory on the primary storage device and eliminates the other problems inherent in the use of a high water mark approach in a highly parallel environment. Unlike prior systems employing a high water mark approach, the invention handles error conditions or interrupts by changing to a backup state and performing archiving operations, rather than causing the system to fail, and without affecting other processes that may exist. Thus, the invention allows an arbitrary number of parallel processes to execute without the need for recomputation and interprocess communications when a process is added or removed, thereby permitting a substantially unlimited number of parallel processes to share a single storage device.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and further advantages of the invention may be better understood by referring to the following description in conjunction with the accompanying drawings, in which:

Figure 1 illustrates a general view of the networked computer system;

Figure 2 shows a flow chart of the process steps of a method according to the invention without the use of a state indicator;

Figures 3A and 3B show different states of operation of a primary storage device; and

Figure 4 shows a flow chart of the process steps of a method according to the invention with the use of a state indicator.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENT

Referring to FIG. 1 of the drawings, reference numeral 10 designates generally a networked computer system having a communication network 12 linking together at least one primary storage device 14, at least one secondary storage device 16 and at least one computer device 18. Communication network 12 can be a local-area network, high-speed bus or other interconnecting mechanism for exchanging messages and data, such as AppleTalk, Ethernet or Token Ring.

Storage devices 14 and 16 can each be a specialized storage device designed for the efficient storage, archival and retrieval of data, or can be a computer augmented with greater storage volumes and devices or can be a minicomputer or large computer providing storage service in addition to other functions. A primary storage device 14 has a memory 21 and a central processing unit ("CPU") 22. An external memory storage unit 23 having a memory 24 may be connected to the primary storage device 14. Preferably, the secondary storage device 16 is a parallel processor such as a Cray Y-MP2E/232 (Cray Research, Cray Research Park, Eagan, MN) connecting with one or more external storage devices 20 such as a tape robot 20a or an optical disk unit 20b.

Computer devices 18 can be any of personal computers, workstations, minicomputers or large computers, or other specialized computing devices or peripherals attached to the communication network. A computer device 18a includes a memory 25 and a central processing unit ("CPU") 26. A computer device 18a may include a plurality of disks (not shown) or other storage resources, each having a memory.

As shown in FIG. 2, a process or a plurality of parallel processes are created to transfer data among computer devices, primary storage devices and secondary storage devices. At block 27, if there is a computer device to be backed up, then at block 28, each process attempts to transfer data from a computer device to a primary storage device. At decision block 29, if an error condition or interrupt was encountered during that data transfer, then, at block 30, that process begins transferring data from the

primary storage device to the secondary storage device or that process creates another process to perform the data transfer.

At decision block 31, if an error condition or interrupt was encountered during the transfer of data from the primary storage device to the secondary storage device, then that process is terminated. Alternatively, that process could try to backup another computer device at decision block 27. If at decision block 31 an error condition was not encountered, then at decision block 32 if there is more data to transfer from the primary storage device to the secondary storage device, data is transferred at block 30. If at decision block 32 there is no more data to transfer, then if at decision block 27 there is another computer device to be backed up, data is transferred from that computer device to the primary storage device at block 28. If at decision block 27 there are no more computer devices to be backed up then the process is terminated. If at decision block 29 an error condition or interrupt was not encountered then the process tries to backup another computer device at block 27.

FIGS. 3A and 3B show a state indicator 38. In FIG. 3A the state indicator 38 is stored in the memory 24. Alternatively, as shown in FIG. 3B, the state indicator 38 may be stored in memory 21.

The state indicator 38 has at least a first state and a second state, the second state is a backup state indicating that data should be transferred from the primary storage device 14 to the secondary storage device 16. For example, the state indicator may be a boolean value having a first state equal to zero and a second state equal to non-zero. The state indicator 38 may have any number of states, as long as at least one of the states indicates that a data transfer from the primary storage device 14 to the secondary storage device 16 (FIG. 1) should occur.

The state indicator 38 is set to the backup state when an interrupt or error condition occurs or is otherwise indicated.

Preferably, memory 21 also contains a number of processes indicator 40, indicating the number of processes which are currently performing data transfer 16. When the state indicator 38 is not in the backup state, i.e. a transfer from the primary storage device to the secondary storage device is not indicated, the number of processes indicator is preferably set to a value such as zero, a null value, etc. which indicates that there are not any processes performing data transfer operations from the primary storage device to the secondary storage device

In use as shown in FIG. 4, a state indicator 38 and a number of processes indicator 40 for indicating the number of processes performing data transfer operations from a primary storage device to a secondary storage device are initialized.at box 45. CPU 22 starts a process or a plurality of parallel processes at box 46 for backing up the data in memory 25 of a computer 18a. These processes may be started at any time, box 47, and typically are created in such a way as to substantially continuously perform

backup operations. The number of processes for performing such backup operations can be determined by the length of time it takes for each process to complete its operations or tasks, and to a lesser extent, by the ratio of data produced by each process to the storage capacity of the primary storage device 12.

At decision block 50, each process checks the value of the state indicator 38. If the state indicator 38 is not in the backup state, the process at box 51 transfers data from the computer device 18a to the primary storage device 12. If at decision block 54 an error condition occurs or is otherwise indicated or some other type of interrupt occurs, the state indicator is set to the backup state. Otherwise, the process terminates or, alternatively, performs backup operations, box 55, on another computer device, disk, or other storage resource.

On the other hand, if at decision block 50 the state indicator 38 is in the backup state, then at decision block 52 the process compares the number of processes indicator 40 to a predetermined maximum number of processes value. This maximum value may depend on the type of external storage devices 20 (FIG. 1) connected to the secondary storage device 16. If the device 20 is a tape drive, then the maximum number of processes can depend on the number of read/write heads on that drive, since each process generally requires two read/write heads. If the device 20 is an optical disk, then the number of processes can be limited by the throughput and speed of the device.

At decision block 52, if the number of processes indicator 40 is less than the maximum number of processes, the process will increment the number of processes by one, box 53, and then transfer data from the primary storage device 14 to the secondary storage device 16, box 57. At decision block 56, if the data transfer was completed without an error condition or interrupt occurring and there is more data to transfer at decision block 58, the process continues transferring data from the primary to the secondary storage device. If at decision block 58 there is not any more to transfer from the primary to the secondary storage device, the state indicator 38 and the number of processes indicator 40 are reset, box 59, and the process terminates. If at decision block 56 an error condition or interrupt was encountered then the process terminates.

If at decision block 52 the number of processes indicator 40 is equal to or exceeds the maximum number of processes value, then the process will transfer data from the memory 25 of the computer device 18 to the memory 21 of the primary storage device 14.

There are other equivalent means for determining whether the number of processes currently transferring data from storage device 14 to storage device 16 has reached a predetermined maximum number of processes. For example, a counter could be set to the maximum number and then decreased each time before a new process begins transferring data from device 14 to device 16. When the counter reaches

zero, the maximum has been reached. There are other equivalent means which would be obvious to someone skilled in the relevant art and which fall within the spirit and scope of this invention. Additionally, it is possible to implement the invention without tracking the number or state of concurrent processes. For example, the number of processes may be determined by hardware or other resource limitations, rather than by a number of processes indicator 40.

If the process performs backup operations which complete the data transfer from the primary storage device 14 to the secondary storage device 16, the process resets the state indicator 38 to a state other than the backup state, preferably the first state, and resets the number of processes indicator 40 to indicate that no processes are currently transferring data from device 14 to device 16. Preferably, indicator 40 is set to zero.

If at decision block 52 the number of processes transferring data from the primary to the secondary storage device are equal to or greater than the maximum number allowed, the process transfers data from the computer device 18a to the primary storage device 12. If at decision block 54 an error condition occurs or is otherwise indicated or some other type of interrupt occurs, the state indicator is set to the backup state, box 55.

Preferably, processes which are performing data transfer operations from a computer device to the primary storage device 12 continue to perform these operations even after the backup state is indicated, as long as there is available storage space on the primary storage device to accommodate the data transfers.

The foregoing description has been limited to a specific embodiment of this invention. It will be apparent, however, that variations and modifications may be made to the invention with the attainment of some or all of its advantages. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

CLAIMS

We Claim:

1. A method for transferring data in a networked system having a computer device coupled to a first storage device having a memory and connecting to a second storage device, said method comprising the steps of:

transferring data from a computer device to a primary storage device until an error occurs; and

transferring data from a primary storage device to a secondary storage device after an error occurs.

2. A method defined in claim 1 further comprising the steps of:

setting a state indicator from a first state to a second state when an error occurs or is otherwise indicated, the second state indicating that a data transfer from the first storage device to the second storage device should occur; and

checking the value of the state indicator and if the state indicator is not in the second state, transferring data from a computer device to the first storage device,

and if the state indicator is in the second state, transferring data from the first storage device to the second storage device.

3. A method for transferring data in a networked system having a computer device coupled to a first storage device having a memory and connecting to a second storage device, said method comprising the steps of:

setting a state indicator from a first state to a second state when an error occurs or is otherwise indicated, the second state indicating that a data transfer from the first storage device to the second storage device should occur; and

creating new processes, each process checking the value of the state indicator

and if the state indicator is not in the second state, transferring data from a computer device to the first storage device,

and if the state indicator is in the second state, transferring data from the first storage device to the second storage device.

4. A method for transferring data in a networked system having a computer device coupled to a first storage device having a memory and connecting to a second storage device, said method comprising the steps of:

counting the number of processes currently transferring data from the first storage device to the second storage device;

setting a state indicator from a first state to a second state when an error occurs or is otherwise indicated, the second state indicating that a data transfer from the first storage device to the second storage device should occur; and

creating new processes, each process checking the value of the state indicator and if the state indicator is not in the second state, transferring data from a computer device to the first storage device,

and if the state indicator is in the second state, comparing the number of processes currently transferring data from the first storage device to the second storage device to a predetermined maximum number of processes,

and if that current number of processes transferring data from the first storage device to the second storage device is greater than or equal to the maximum number of processes, setting the state indicator to a state other than the second state and transferring data from a computer device to the first storage device,

and if that current number of processes transferring data from the first storage device to the second storage device is less than the maximum number of processes, transferring data from the first storage device to the second storage device.

5. A method defined in claim 4 wherein said error condition occurs during a write operation to said memory of said first storage device.

6. A method for transferring data in a networked system having a computer device coupled to a first storage device having a memory and connecting to a second storage device, said method comprising the steps of:

transferring data from a computer device to a primary storage device until an interrupt occurs; and

transferring data from a primary storage device to a secondary storage device after an interrupt occurs.

7. A method defined in claim 1 further comprising the steps of:

setting a state indicator from a first state to a second state when an interrupt occurs or is otherwise indicated, the second state indicating that a data transfer from the first storage device to the second storage device should occur; and

checking the value of the state indicator and if the state indicator is not in the second state, transferring data from a computer device to the first storage device,

and if the state indicator is in the second state, transferring data from the first storage device to the second storage device.

8. A method for transferring data in a networked system having a computer device coupled to a first storage device having a memory and connecting to a second storage device, said method comprising the steps of:

setting a state indicator from a first state to a second state when an interrupt occurs or is otherwise indicated, the second state indicating that a data transfer from the first storage device to the second storage device should occur; and

creating new processes, each process checking the value of the state indicator

and if the state indicator is not in the second state, transferring data from a computer device to the first storage device,

and if the state indicator is in the second state, transferring data from the first storage device to the second storage device.

9. A method for transferring data in a networked system having a computer device coupled to a first storage device having a memory and connecting to a second storage device, said method comprising the steps of:

counting the number of processes currently transferring data from the first storage device to the second storage device;

setting a state indicator from a first state to a second state when an interrupt occurs, the second state indicating that a data transfer from the first storage device to the second storage device should occur; and

creating new processes, each process first checking the value of the state indicator

and if the state indicator is not in the second state, transferring data from a computer device to the first storage device,

and if the state indicator is in the second state, comparing the number of processes currently transferring data from the first storage device to the second storage device to a predetermined maximum number of processes,

and if that current number of processes transferring data from the first storage device to the second storage device is greater than or equal to the maximum number of processes, setting the state indicator to a state other than the second state and transferring data from a computer device to the first storage device,

and if that current number of processes transferring data from the first storage device to the second storage device is less than the maximum number of processes, transferring data from the first storage device to the second storage device.

10. An apparatus for transferring data in a networked computer system, said apparatus comprising:

a first storage device having a central processing unit and a memory;

a second storage device having a plurality of external memory devices connected thereto;

a plurality of computer devices having a central processing unit and a memory;

means for networking together said first storage device, said second storage device and said plurality of computer devices, said networking means permitting the transfer of data from said plurality of computer devices to said first storage device and from said first storage device to said second storage device;

a state indicator in said memory of said first storage device, said state indicator having at least a first state and a second state, said second state indicating the need for a data transfer from said first storage device to said second storage device; and

means for setting said state indicator to said second state when an error occurs or is otherwise indicated.

11. An apparatus for transferring data in a networked computer system, said apparatus comprising:

a first storage device having a central processing unit and a memory;

a second storage device having a plurality of external memory devices connected thereto;

a plurality of computer devices having a central processing unit and a memory;

means for networking together said first storage device, said second storage device and said plurality of computer devices, said networking means permitting the transfer of data from said plurality of computer devices to said first storage device and from said first storage device to said second storage device;

a state indicator in said memory of said first storage device, said state indicator having at least a first state and a second state, said second state indicating the need for a data transfer from said first storage device to said second storage device;

means for setting said state indicator to said second state when an error condition is encountered during a write operation to said memory of said first storage device; and

means for counting the number of processes currently transferring data from said first storage device to said second storage device and comparing that number to a predetermined maximum number.

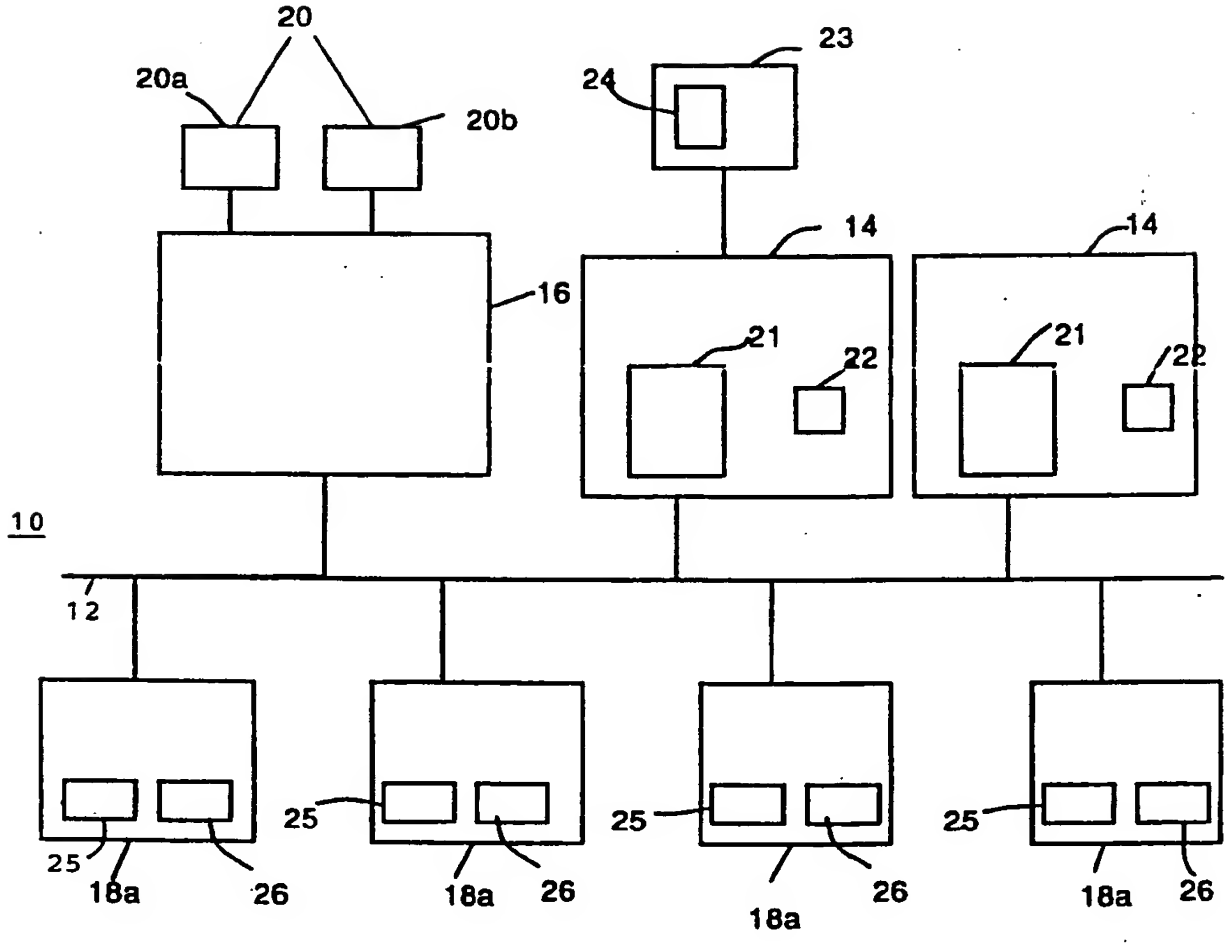
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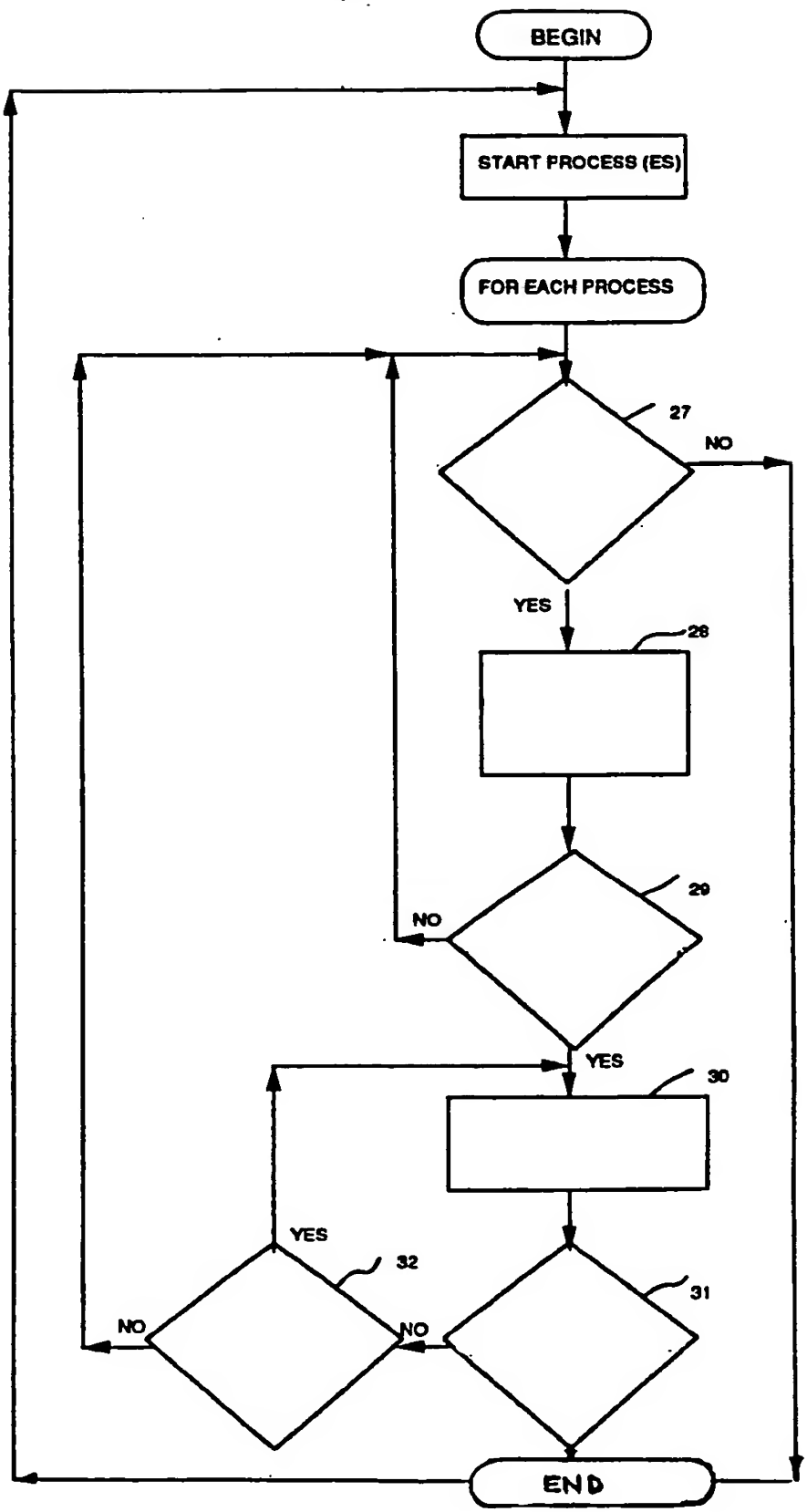
FIG. 1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FOR EACH PROCESS
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END

FIG. 2

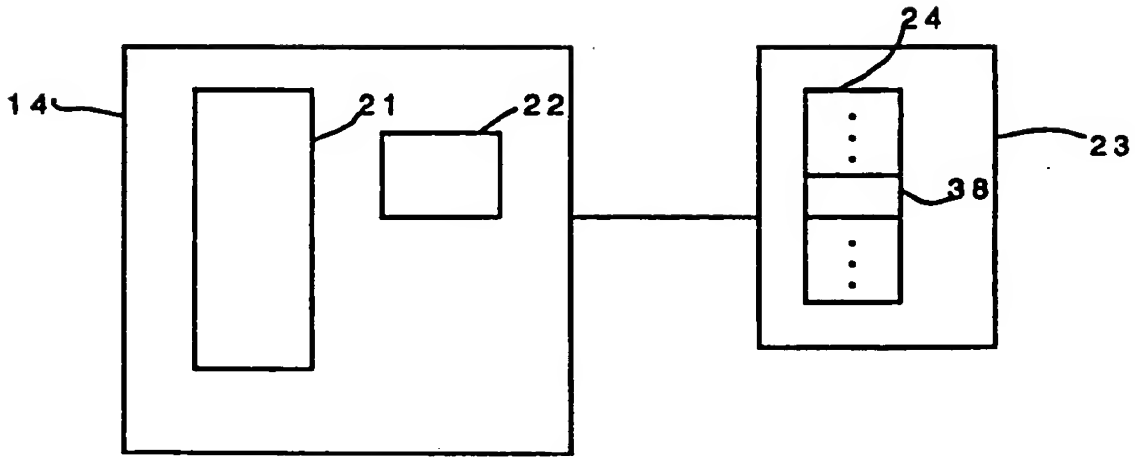


FIG. 3A

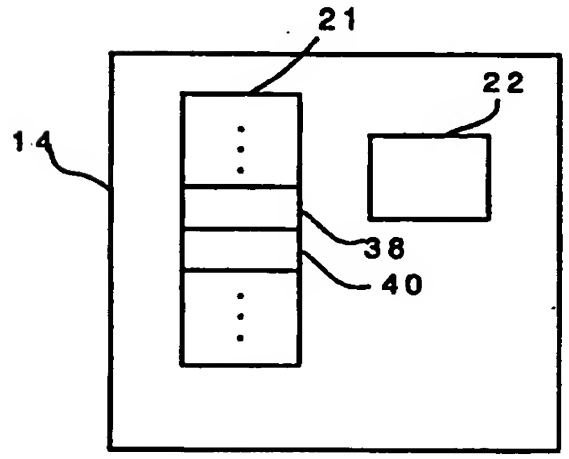
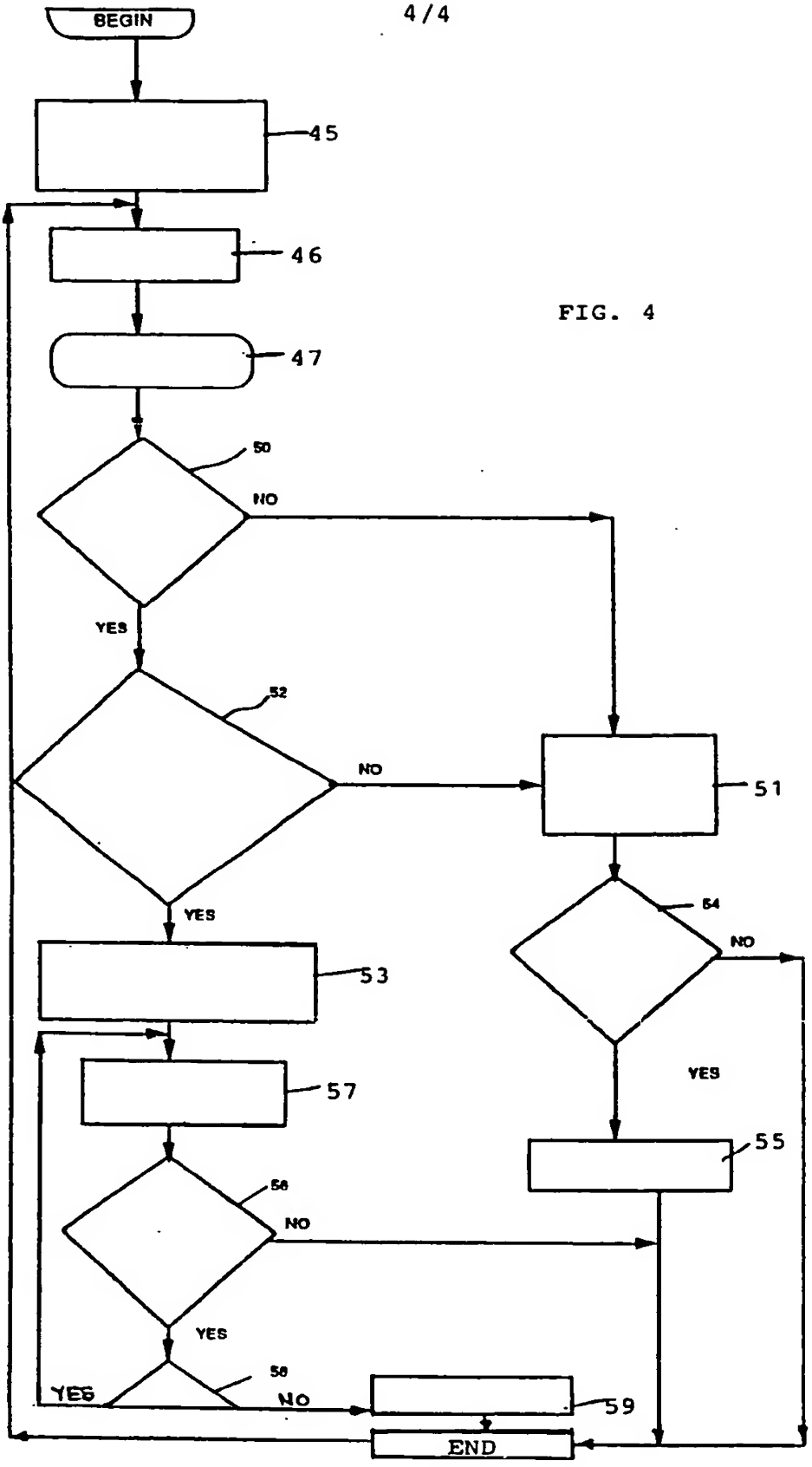


FIG. 3B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58
YES
NO
59
END

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/00761

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G06F11/14 G06F12/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP,A,0 259 912 (HEWLETT-PACKARD) 16 March 1988 see column 18, line 30 - column 20, line 55; figures 12,13 see column 23, line 49 - column 27, line 37; figures 16A,16B ---	1-11
Y	WO,A,92 14204 (GIGATREND INC.) 20 August 1992 see abstract see page 7, line 26 - page 8, line 35; figure 2 ---	1-11
A	EP,A,0 359 384 (COMPAQ COMPUTER CORP.) 21 March 1990 see column 4, line 3 - column 6, line 51 --- -/--	1-3,6-8, 10,11

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13 June 1994	21 JUN 1994

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Nielsen, O

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